A Super-Neutrino Beam from BNL to Homestake

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Presented at NuFact 02

http://pubweb.bnl.gov/people/kahn/talks/bnlHomestake.pdf

AGS Upgrade to Proton Driver

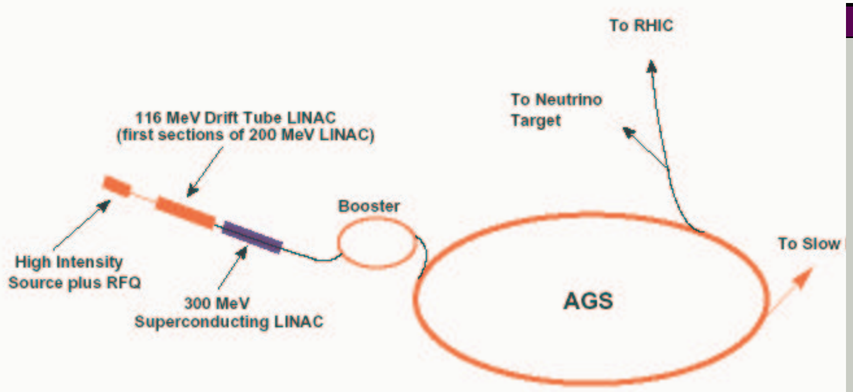


Figure 15: Layout of the AGS facility with the addition of the super conducting LINAC.

Parameter	Now	Phase I	Phase II
		2.5 GeV Accumulator	2.5 Hz
Linac Energy (MeV)	200	400	400
Booster Intensity	1.5×10^{13}	2.0×10^{13}	2.0×10^{13}
Booster Energy (GeV)	1.8	2.5	2.5
Booster Cycles	4	6	6
AGS Energy (GeV)	24	28	28
AGS Intensity (TP/sec)	36	120	300
AGS Rep Rate (Hz)	0.6	1.0	2.5
AGS Current (μA)	5.6	19	48
AGS Intensity (ppp)	6×10^{13}	12×10^{13}	12×10^{13}
AGS Power (MW)	0.14	0.53	1.3
Incremental Cost (M$)	–	65	54

Machine	Power	Proton/Pulse	Repetition Rate	Protons/SSC year
Current AGS	0.14 MW	6×10^{13}	0.625 Hz	3.75×10^{20}
AGS Proton Driver	1.3 MW	1.2×10^{14}	2.5 Hz	3.0×10^{21}
Japan Hadron Facility	0.77 MW	3.3×10^{14}	0.29 Hz	9.6×10^{20}
Super AGS Prot Driver	4 MW	2×10^{14}	5.0 Hz	1.0×10^{22}

ν Oscillation Physics Agenda

1. Precise measurement of Δm^2_{32}.
   - Disappearance experiment with good energy resolution.
2. Measurement of θ_{13}.
   - Detection of $\nu_\mu \rightarrow \nu_e$ appearance mode.
3. Detection of CP violation in neutrino sector.
   - Detection of asymmetry between $\nu_\mu \rightarrow \nu_e$ and $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ processes.
4. Observation of the *matter enhancement effect* in $\nu_\mu \rightarrow \nu_e$ appearance.
   - Allows the measurement of the sign of Δm^2_{32}.

The Detector for the Very Long Baseline Site

- Very Long Baseline Experiment:
  - Place detector at Homestake Mine in South Dakota 2540 km from BNL.
    - The WIPP site in New Mexico at 2880 km from BNL would be an acceptable alternative.
  - The Homestake site would consist of a cluster of *TEN* 100 kton water Cherenkov detectors. *Five* of these modules would be the minimum acceptable to do reasonable physics.
  - These modules would be beneath the ground so that proton decay physics could also be down.
  - The ν beam would need to be inclined 11.5° from the earth surface for the Homestake site.
  - The ν beam to Homestake would be on axis to obtain the maximum flux.

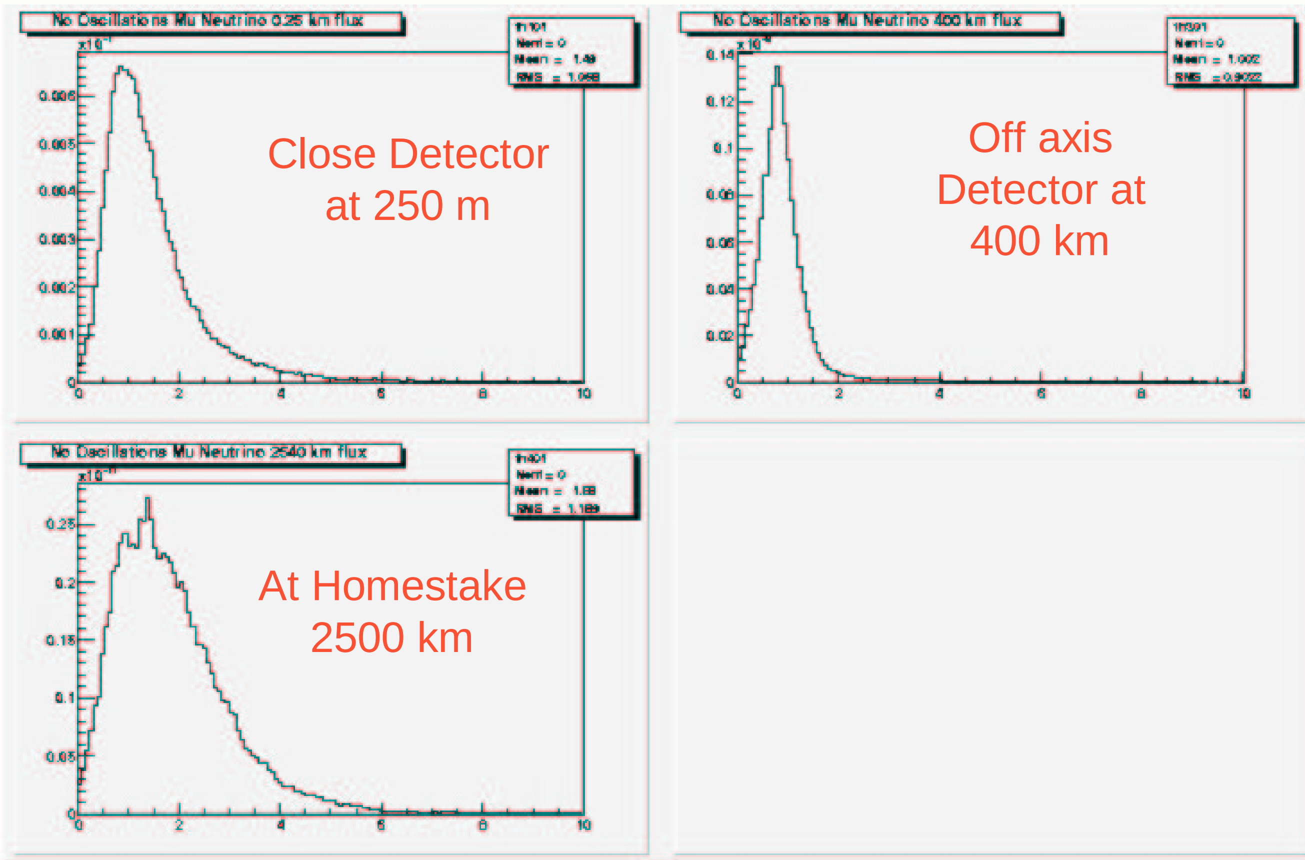
The Detector for the Medium Long Baseline Site

- A desirable location for detector would be at the first maximum for oscillations.
  - If Δm^2_{32}=0.003 eV^2 and $<E_\nu>\approx$1GeV, the first oscillation maximum is at 412 km.
- Placing the detector 1.5° off axis for the BNL ν beam would produce a narrow spectrum peaked at 1GeV.
- Possible detector choices for *Medium Long Baseline* experiment:
  - 25 kton Liquid Argon TPC detector (note: LOI states only 10 ktons.)
  - 100 kton Water Cherenkov detector.
  - Both of these detectors are similarly priced (according to NuMI off-axis LOI.)
- This detector should produce a precise measurement of Δm^2_{32} and produce the best measurement of θ_{13}. It may also be sensitive to CP violations (depending on the parameters).

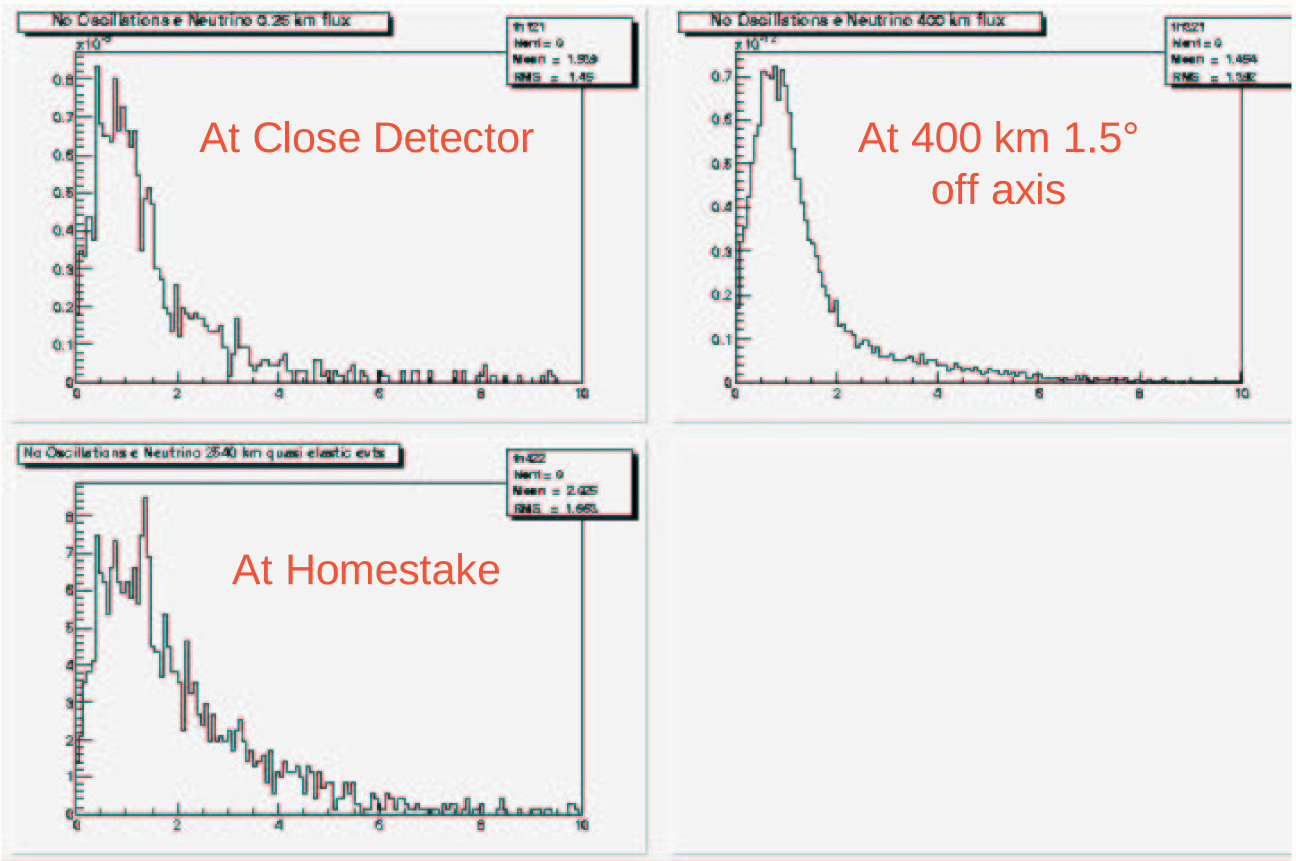
The Close-In Detector

- A close-in detector is needed to provide reliable ν beam alignment.
- This detector could be placed ~220 meters from the target behind the muon stop. It could be below the water table assuming ν interactions do not contaminate the ground water.
- An ideal choice would be a 0.33 kton Liquid Argon TPC detector.
  - A detector of this size has already been built.
  - This detector would be immersed in a 0.5 T magnetic field to determine the lepton charge.
- Such a detector would provide an accurate description of the ν beam composition.
  - The good electron identification of LiqAr is important for this.
- This detector would produce a very high statistics, high resolution data sample for non-oscillation physics.

Non Oscillated ν_μ Flux at Detector Locations



ν_e Flux Contamination Seen at Various Detector Sights



Event Estimates Without Oscillations

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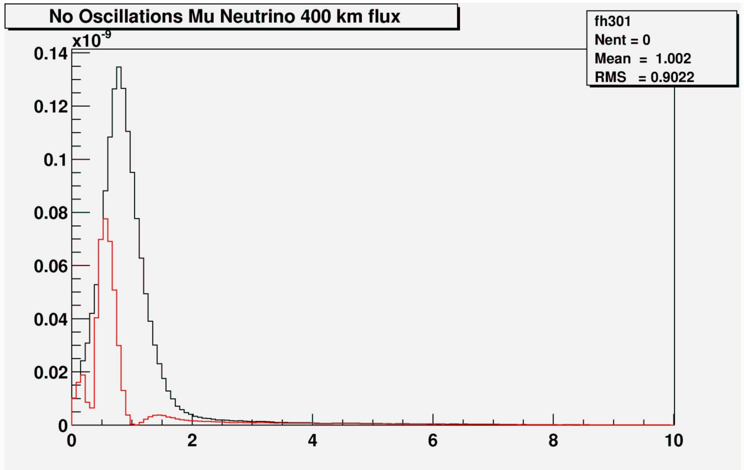
- The table below shows estimates for *quasi-elastic events* expected at the different detectors.
  - The source is a 1.2 MW proton driver.
  - The experiment takes data for 5 Snowmass Years. (5×10^7 sec.)
  - The horn is set for ν production:

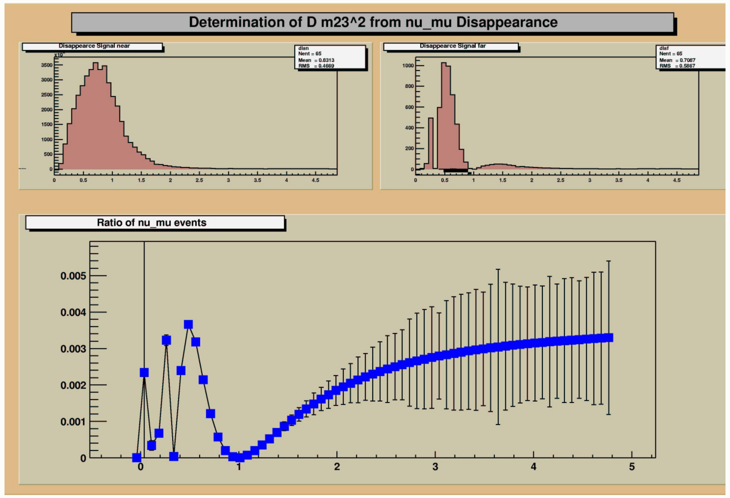
Detector Position	Detector Mass	$\nu_\mu n\rightarrow\mu^- p$	$\nu N\rightarrow\nu N\pi^\circ$	$\nu_e n\rightarrow e^- p$
At 250 m	0.33 kton	1.45×10^9	2.19×10^8	1.80×10^7
At 400 km H_2O	100 kton	45812	5476	564
At 400 km Ar	25 kton	11453	1369	141
Homestake	1 megaton	26179	4531	233

  - We certainly could do decent physics at an earlier phase with 0.5 MW machine and ½ the proposed detector mass.
  - The horn is set for $\bar{\nu}$ production:

Detector Position	Detector Mass	$\nu_\mu p\rightarrow\mu^+ n$	$\nu N\rightarrow\nu N\pi^\circ$	$\nu_e p\rightarrow e^+ n$
At 250 m	0.33 kton	2.96×10^8	5.15×10^7	3.40×10^6
At 400 km H_2O	100 kton	9840	1372	123
At 400 km Ar	25 kton	2460	343	30.6
Homestake	1 megaton	5409	1080	40.4

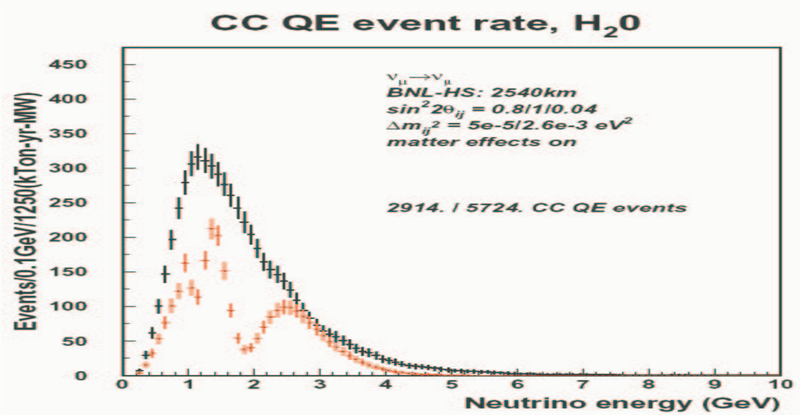
Determination of Δm_{32}^2 by Disappearance

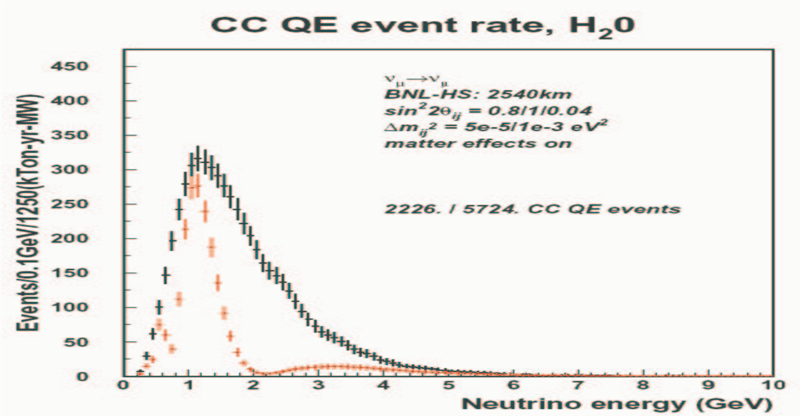




- A precise measurement of Δm_{32}^2 can be obtained by comparing the flux at the 400 km detector to the flux seen at the close-in detector.
- Upper figure shows the non-oscillated flux and the flux corresponding to $\Delta m_{32}^2 = 0.0035\ \mathrm{ev}^2$.
- The lower figure shows the ratio of the far to near detectors with statistical error bars.
- Fermi motion at low E_ν and resolution can limit the quality of this measurement.

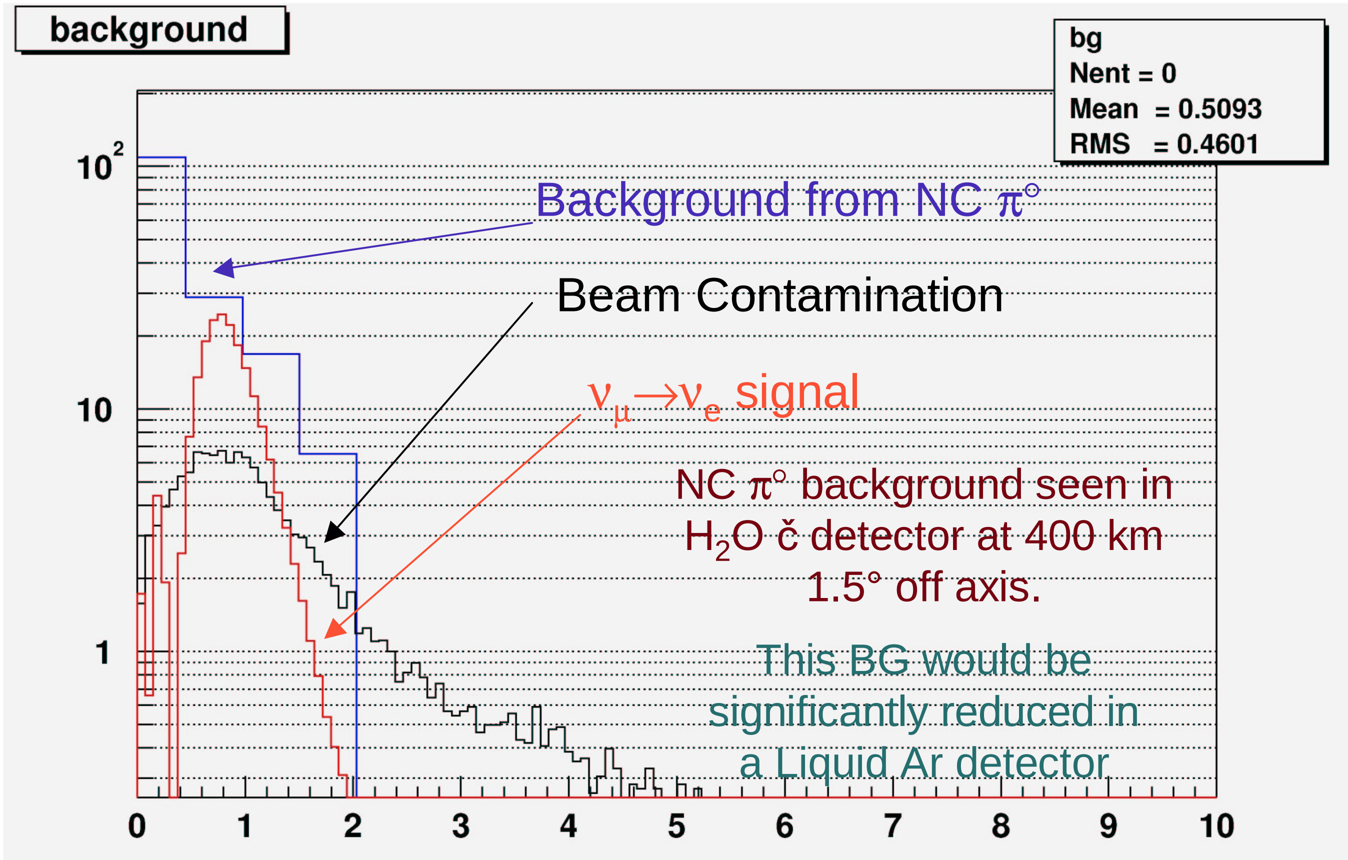
Δm_{32}^2 by Disappearance from BNL to Homestake





- Figures on the left show the spectra of quasi-elastic events seen at the Homestake Mine (2540 km from BNL) for a ½ MT H_2O č detector and 0.5 MW proton beam.
  - Upper figure shows Δm_{32}^2=0.0026 eV^2.
  - Lower figure shows Δm_{32}^2=0.001 eV^2.
- The figures include a 10% energy resolution to for both measurement errors and nuclear effects.
- Matter effects are included in these figures.
- Errors indicate the sensitivity expected for 5 Snowmass years of running.

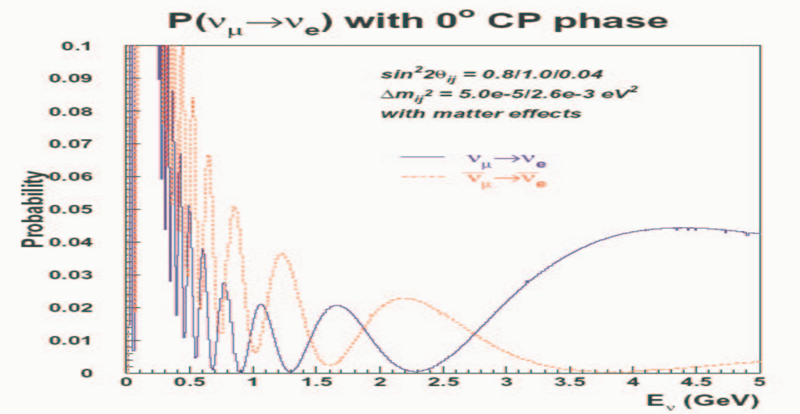
Background to Appearance Signal

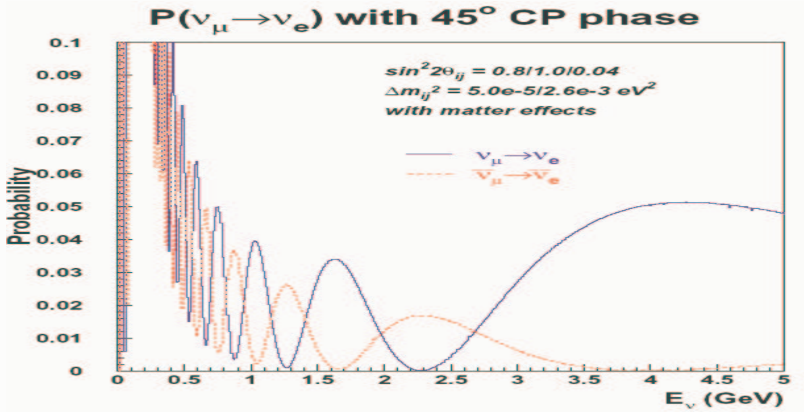


Detector Backgrounds for the Appearance Signal

- There are two important background sources for the appearance signal:
  - ν_e contamination in the ν_μ beam from K_{e3} and μ decay.
    - This appears to be ~1% for both the 400 km off-axis detector and the Homestake detector.
  - Background from $\nu N \rightarrow \nu\pi^\circ N$ events where the π° decay asymmetrically such that only one photon is seen and is confused for an electron.
    - The $\nu\pi^\circ N$ background is particularly difficult for 1 GeV $<E_\nu<$2 GeV.
      - Choosing the 1.5° off-axis beam for the 400 km detector lowers $<E_\nu>$ to ~0.9 GeV.
    - How to reduce this background will have an influence on the detector choice.
      - Liquid Argon should have good photon identification and have a better discrimination against the $\nu\pi^\circ N$ background (if it is affordable).
      - Another approach is build a larger H_2O č detector and exclude ν_e candidates below 2 GeV. Also one needs sufficient phototube coverage.
      - These options are being studied and more work needs to be done.

CP Violation and Matter Effects at Homestake





- A very long baseline experiment allows for the study of CP violation and the matter effects associated to ν_e interactions off atomic electrons.
- The figures at the left show the probability ν_e ($\bar{\nu}_e$) appearance no CP violation and maximal CP violation.
  - Δm_{32}^2=0.0026 eV^2 and $\sin^2(2\theta_{13})$=0.04
- The measurement of the CP phase comes from the comparison of ν_e to $\bar{\nu}_e$ appearance rates at different E_ν.

ν_e Appearance at Homestake

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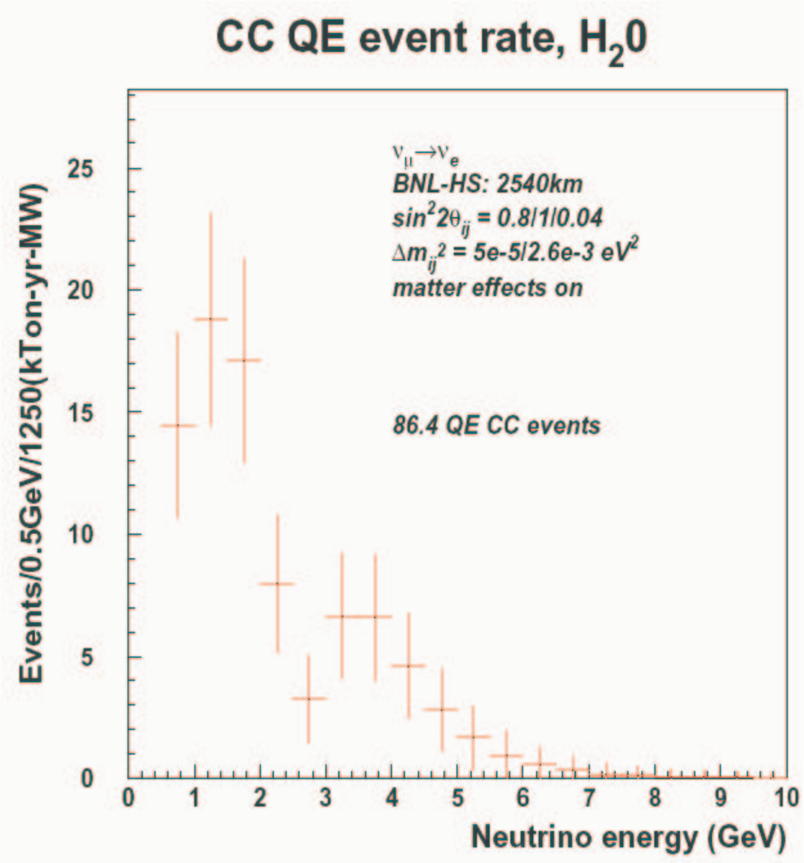

- Figure shows ν_e appearance events at the Homestake mine for 5 Snowmass years with 0.5 MW and a 0.5 Megaton Detector.
  - Δm_{32}^2=0.0026 eV^2 and $\sin^2(2\theta_{13})$=0.04
- The error bars correspond to statistical errors expected.
  - A 10% energy resolution is assumed for reconstruction and nuclear effects.

Oscillated Events at Far Detectors

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- For 1.2 MW proton driver and 25 kton Liq Ar detector at 400 km for a 5×10^7 second running period we would expect:

Oscillations at 400 km for ν

Δm_{32}^2	$\sin^2(2\theta_{13})$	ν_μ QE	ν_e QE signal	ν_e background
No oscillations	—	11453	—	141
0.0025	0.04	2782	197	141
0.0035	0.01	3458	44	141

Oscillations at 400 km for antineutrinos

Δm_{32}^2	$\sin^2(2\theta_{13})$	ν_μ QE	ν_e QE Signal	ν_e background
No oscillations	—	2460	—	30.6
0.0025	0.04	572	43.3	30.6
0.0035	0.01	736	9.6	30.6

- With a 1 megaton H_2O č detector at 2500 km for 5×10^7 second period we would expect:

Oscillations at 2540 km for neutrinos

Δm_{32}^2	$\sin^2(2\theta_{13})$	ν_μ QE	ν_e QE signal	ν_e background
No oscillations	—	26179	—	233
0.0025	0.04	13363	286	233
0.0035	0.01	12690	77	233

Oscillations at 2540 km for antineutrinos

Δm_{32}^2	$\sin^2(2\theta_{13})$	ν_μ QE	ν_e QE signal	ν_e background
No oscillations	—	5409	—	49
0.0025	0.04	2757	59	49
0.0035	0.01	2637	15.8	49

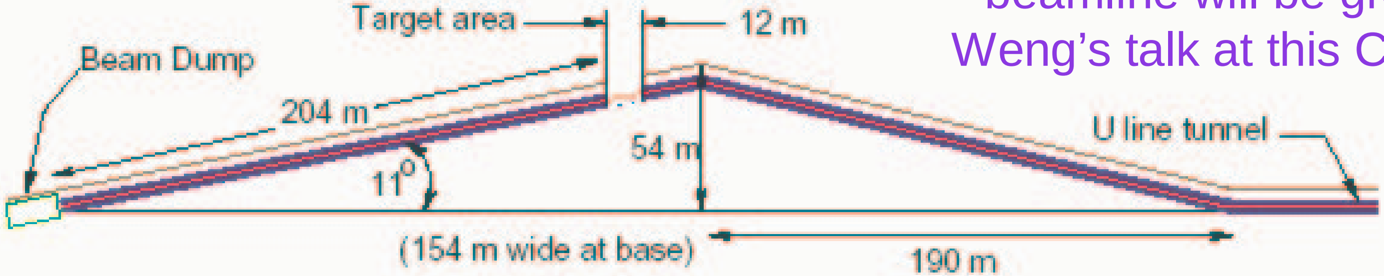
What is Required for this Neutrino Facility

- Upgrades to AGS which could be done in phases:
  - Phase 1 to 0.53 MW: Superconducting Linac upgrade and 2.5 GeV Accumulator.
    - Cost $ 65M
  - Phase 2 to 1.3 MW: AGS+Booster power supplies, RF upgrade.
    - Additional cost $54M →Total AGS upgrade ~$110 M.
- Neutrino Beam Considerations:
  - ν beam must be inclined 11.5° (13.0°) to reach Homestake (WIPP).
  - Only a 1.7° inclined beam is required for the closer Lansing, NY site.
  - Estimated beamline costs are $35M.
- Detector costs:
  - Estimating 100 kton of H_2O č or 25 kton of Liquid Argon from NuMI off-axis detector LOI: (The H_2O č detector cost should be more reliable.)
    - ~ $65M for detector at 400 km.
  - No estimate has been provided for the 1 Megaton detector.

The BNL Hill (Mt. Palmer)

Details of AGS upgrade and ν beamline will be given in Bill Weng's talk at this Conference.

Use BNL-Homestake hill as *eg.*:



Numbers are for BNL-HS hill and ν-beamline. Cheaper for lower dip angle.

Item	Basis	200 m ($$10^6$)	150 m ($$10^6$)
Proton transport	RHIC injector	11.85	11.85
Target/horn	E889	3.0	3.0
Installation/Beam Dump	New	2.67	2.67
Decay Tunnel	E889	0.45	0.45
Conventional const. (hill)	New	8.0	5.0
Conventional const. (other)	E889	9.1	9.1
Total		35.19	32.19

(Dana Beavis, BNL. Letter of Intent to BNL, 2002.)

Brett Viren, BNL - New Initiatives for the NuMI Neutrino Beam, May 2-4, 2002 – p.7/20

Current Status and Conclusions

- A *letter of intent* has been submitted to the BNL management.
- A written *R&D Study Report* which will provide the technical basis for a future proposal will be submitted to the BNL laboratory later this summer.
- Hopefully this new facility can be build for a reasonable expenditure.

Neutrino Oscillation Experiments for Precise Measurements of Oscillation Parameters and Search for $\nu_\mu \to \nu_e$ Appearance and CP Violation.

LETTER OF INTENT to Brookhaven National Laboratory.

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